Hot Summer Nights and Cold Winter Evenings: Demographic Differential Vulnerability to Heat Waves and Cold Spells in the Metropolitan Area of Vienna

Keywords

Environmental demographics, population health, extreme weather, climate change, projections

Abstract

Climate change and its consequences are expected to affect populations worldwide. This study explores the impact of changing environmental conditions on population health in the metropolitan area of Vienna. A particular focus is placed on the effects of thermal hazards, which are predicted to become more severe, especially in fast-growing cities like Vienna. The study has two main objectives: First, we analyze the influences of temperature extremes, i.e. heat waves and cold spells, on morbidity and mortality using historical data on hospitalizations and medical treatments. Second, building on the findings from the first part of the study, we project future climate and population dynamics and estimate the expected health burden for the metropolitan area of Vienna. In addition to accounting for social factors as drivers of differential health vulnerabilities, we also consider structural aspects of the built environment, such as urban density or the availability of green spaces, which can help mitigate the harmful effects of temperature extremes. The expected insights from the study are of high relevance both for academic research and policy makers and have implications for urban planning and public health.

Extended Abstract

As a consequence of climate change, extreme weather events, such as heat waves, cold spells, heavy rainfalls and droughts, are expected to become more frequent and more intense. Indeed, Austria is increasingly affected by changing climatic conditions, particularly with respect to thermal hazards. Since the 1880s, average yearly temperature rose by more than 2°. While Vienna experienced on average 8.9 heat days (i.e. days with a maximum temperature ≥ 30°) in the 1960s and 70s, this number rose to 25.4 heat days in the period since 2010 (City of Vienna 2019). At the same time, the number of tropical nights (i.e. nights with a minimum temperature ≥ 20°) steadily increased. By the end of the century, the average number of heat days and tropical nights per year is expected to increase to more than 50 days and 30 nights on average (Chimani et al. 2016; APCC 2018). Meanwhile, there is also an increasing risk of extremely cold weather, due to unexpected weather situations such as more frequent intrusion of cold Arctic air masses leading to extremely low temperatures (APCC 2014).

These changing climatic conditions impose serious threats to human health. For example, being directly exposed to extreme heat conditions can lead to exhaustion, dehydration, hyperthermia, heat strokes, and exacerbate cardiovascular problems (González-Alonso, Crandall, and Johnson 2008; Michelozzi et al. 2009; Crandall and González-Alonso 2010; Kenny et al. 2010). Likewise, exposure to cold weather can increase morbidity and mortality, particularly by leading to myocardial infarction, ischemia and cardiovascular-, respiratory- and cerebrovascular diseases (Gómez-Acebo, Llorca, and Dierssen 2013; The Eurowinter Group 1997). Impacts on health can also be indirect if they are mediated through the effects of climate on ecosystems, the economy, or institutions and governance (Watts et al. 2018). Indeed, the *Lancet Commission on Health and Climate Change* has warned that "climate change is a medical emergency" (Watts et al. 2015).

Given the urgency of mitigating the adverse impacts of climate change on health, we investigate how changing climatic conditions affect health in the metropolitan area of Vienna. In particular, as novel contributions, we study the role of population heterogeneity and differential vulnerabilities to climatic changes using small-scale district level analysis and projections accounting for both climate and demographic dynamics. This allows us to obtain an integrated picture of the relationship and forecasts of future changes under different scenarios.

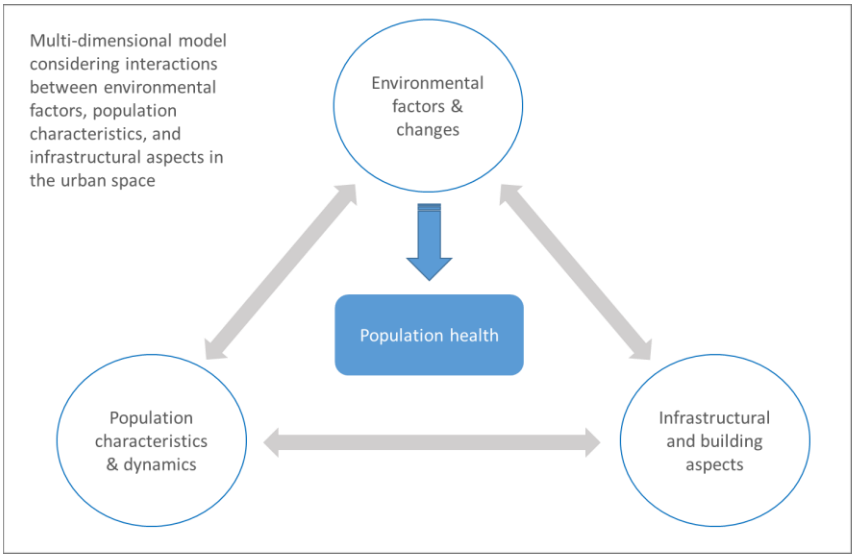

Figure 1. Multi-dimensional model of climate impacts on health.

The triadic relationship between climate change, urban geography and population dynamics we want to disentangle is displayed in Figure 1. Investigating the relationship between temperature extremes and health at the individual and district level, we try to identify high-risk areas. In doing so, we explicitly control for population characteristics to better understand how different sub-populations are affected by climate hazards. Second, we link district-level projections of future population by age, sex, and level of education to climate projections for the metropolitan area of Vienna. This demographic approach to impact assessments emphasizes the need to consider relevant population characteristics and dynamics in studying the challenges arising from climate change (Lutz and Muttarak 2017). Both aims represent novel contributions to the field of population and environment research. In addition to its academic relevance, the study has strong policy implications with respect to public health and urban planning.

Research on the effects of weather extremes on population health is challenged by various factors, such as the availability of high-quality, high-resolution data. To gain access to population and health information, we closely cooperate with different partners in Vienna, such as the City of Vienna, the Federal Social Insurance Association (Hauptverband), and the Gesundheit Österreich GmbH (GÖG). Modeling environmental effects on health is further challenged by the complex interactions between health, population and policy responses which may change over time. In our modeling strategy, we explicitly capture the effects of non-environmental factors and account for contextual dynamics. In particular, in our projections, we attempt to explicitly incorporate different future scenarios, taking both population and environmental changes, as well as policy responses into consideration.

Literature Review

Broad scientific evidence suggests that heat days have already significantly raised the risk of premature mortality, especially for the elderly and females (APCC 2018). In the absence of adaptation, heat-related mortality in Vienna in the latter half of the century can be up to 129 % higher as compared to the period 1970-2000 (Muthers, Matzarakis, and Koch 2010). Evidence from other countries shows that hospital admissions due to cardiovascular and respiratory conditions significantly increase in response to heat waves (Rocklöv and Forsberg 2009; Gronlund et al. 2014). Meanwhile, cold spells can have public health impacts of a similar magnitude (Healy 2003; Kysely et al. 2009). Studying the effects of cold weather on mortality across 15 European cities, Analitis et al. (2008) therefore warn public health authorities of underestimating cold-related mortality because of the exclusive focus on heat episodes.

Importantly, population groups are not equally affected by temperature extremes, but are characterized by differential vulnerability, which is a function of exposure, sensitivity and adaptive capacity (IPCC 2014). Exposure refers to the presence of people in places that are at risk of being adversely affected, while sensitivity relates to the degree to which a population group is negatively affected once a shock occurs. Adaptive capacity is the ability to cope with consequences and adjust to climate change. As emphasized by the recent APCC Special Report on *Health, Demography and Climate Change* (APCC 2018), population dynamics and structure lie at the heart of climate change vulnerability.

Indeed, demographic changes will likely lead to an increase in the potential risk groups in Austria. While population growth has rejuvenated Vienna's population age structure in recent decades, the number of elderly people continues to increase in absolute terms (See Figure 2). Due to the aging of the large baby boomer cohorts, more people will live with chronic health problems and disabilities in the future and thanks to the favorable living conditions that attract many newly arriving citizens, the Viennese live to increasingly higher ages. As urbanization and the number of elderly increases, the threat of heat-related mortality will become more severe. In order to design efficient policy interventions, it is important to identify *who* is vulnerable and to *what* climatic hazards (Zagheni, Muttarak, and Striessnig 2016; Muttarak, Lutz, and Jiang 2016).

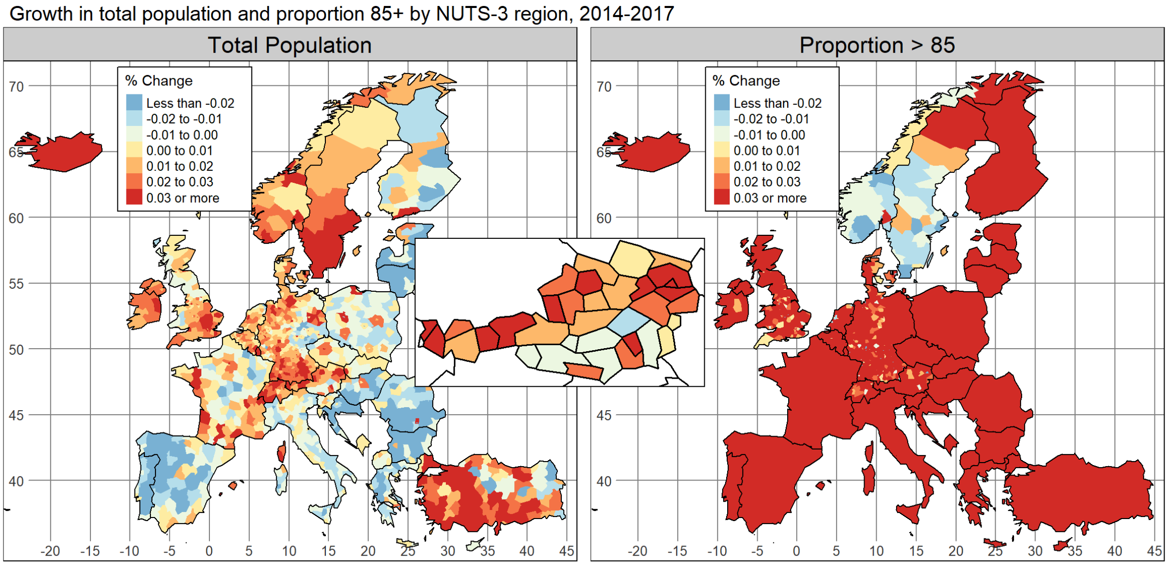

Figure 2. Growth in total population and proportion of older people (>85) by NUTS-3 region.

That older populations are more vulnerable to temperature extremes due to a declining ability for thermoregulation is well-established (Baccini et al. 2008; Wanka et al. 2014; Kenny et al. 2017). However, socioeconomically disadvantaged individuals are also more vulnerable to temperature extremes (Hansen et al. 2013; Klein Rosenthal, Kinney, and Metzger 2014). Social and economic disparities, cultural norms, language barriers and physiological and psychosocial factors influence the capacity to respond and adapt to extreme climate events. A factor, which is closely mirroring socioeconomic status and which has been found to be highly relevant in the context of adaptation to changing climatic conditions, is education (Lutz, Muttarak, and Striessnig 2014; Muttarak and Lutz 2014). Not only are higher educated individuals better prepared in the case of emergencies resulting from extreme weathers (Pichler and Striessnig 2013; Hoffmann and Muttarak 2017), communities with higher proportions of well-educated individuals also experience lower risk from climatic hazards (Muttarak and Pothisiri 2013; Wanka et al. 2014; Witvorapong, Muttarak, and Pothisiri 2015). This aspect is especially relevant for the City of Vienna where vast differences in educational attainment across districts persist. Therefore, when analyzing differential vulnerabilities to environmental hazards, our analyses will take all mentioned sociodemographic factors into account.

The growth in city population and increased economic activity also leads to changes in urban land cover. Densely-populated areas and intensifying traffic result in urban heat islands (UHI) where temperatures exceed those in the surrounding countryside. With the aim of reducing the potential health impact, the City of Vienna has developed the *Urban Heat Islands Strategieplan* (Brandenburg et al. 2015).To successfully manage the health effects of climate change, however, an empirical assessment of how climate change interacts with demographic dynamics and the urban infrastructure (e.g. building density, green spaces) at small spatial scales is needed (APCC et al. 2018). Whilst there is abundant literature on the health impacts of extreme weather, most studies are carried out at a relatively large spatial scale, such as the city or country level, and fail to account for temperature differences within urban spaces. In our spatial models, we focus on vulnerability differences within Vienna explicitly taking the role of sociodemographic and infrastructural characteristics of different districts and communities into consideration.

Finally, while our understanding of past health impacts from weather extremes is steadily increasing, not many studies consider how population dynamics (e.g. by age, gender, education) influence vulnerability to climate extremes in the future. For a city to plan mitigation of negative health impacts from future extreme temperatures, knowledge on spatial distribution and composition of the population, as well as characteristics of the built environment, urban density, distance to green spaces and large water bodies is vital. To this end, **this study aims to provide a better understanding of the impacts of temperature extremes on health, focusing on spatial heterogeneity at the district level of the city of Vienna, considering differential vulnerability by subgroups of population and infrastructural factors.**

Data and Methods

The paper consists of two main parts. In the first part, we study the relationship between extreme temperature events and health under consideration of social and structural aspects using historical data. In the second part, which builds on the first part, we predict future developments under different climate and population scenarios.

Data

Environmental data is derived from the StartClim and TAWES datasets, which provide daily weather statistics from weather stations in and around Vienna. The data is available from the Austrian weather service ZAMG (Zentralanstalt für Meteorologie und Geodynamik). This local data is complemented with publicly available data from the CRU TS series (Climatic Research Unit Timeseries, University of East Anglia), which provides daily weather information on maximum and minimum temperatures, precipitation, and cloud cover at small spatial resolution since 1901.

The health data are obtained through the Federal Social Insurance Association (Hauptverband), where daily statistics on deaths as well as hospitalization and treatments in medical practices are collected for accounting purposes. The data contains information on registered patients' places of residence, allowing us to link the health information to environmental conditions in the districts and communities in and around Vienna. Moreover, the data contain information according to the International Classification of Diseases (ICD) on the specific symptoms for which patients were treated, or – in the case of mortality – causes of death. This enables us to check the specific health threats through which temperature extremes affect human well-being. Detailed information on past population at risk for the districts of Vienna, as well as surrounding communities can be obtained from Statistics Austria. Generalized illustrations of past land use and development plans can be accessed through the website of the City of Vienna (MA 21 - Stadtteilplanung und Flächennutzung 2019) and will be complemented by maps of imperviousness density derived from remote sensing information (Sannier et al. 2016; Lefebvre, Sannier, and Corpetti 2016).

Methods

The first set of analyses uses spatial demographic methods to obtain estimates of the effect of temperature extremes on population health for the metropolitan area of Vienna (which we define as the City of Vienna plus the districts within 20km of its perimeters). Both the daily weather and health information date back to the 1980s, allowing us to study trends over time and to employ panel methods controlling for spatial fixed effects and seasonality. We study two main health outcomes: morbidity (proxied with data on cause-specific and all-cause hospitalizations and treatments in medical clinics) and cause-specific and all-cause mortality. The outcomes are analyzed for the separate districts and communities in and around Vienna, which form the spatial units in our analysis. Poisson and negative-binomial models will be used to account for the particular properties of the mortality and morbidity distributions (right-skewed with zero-inflation). The analysis is enriched by social and structural factors, which describe the demographic composition and characteristics of the neighborhoods.

The second part of the paper builds upon the outcomes of the first part, combining the estimated health impact of temperature extremes with projections of the future population of Vienna and its surroundings at the district level by age, sex, and level of educational attainment. We rely on state-of-the-art multidimensional cohort-component projection methodology outlined by KC, Striessnig et al. (2014). Assumptions regarding future fertility, mortality and migration will be adopted from existing projections by Statistics Vienna (Bauer 2018). However, district level differentials will be dependent on endogenously determined education compositions. Future exposure can then be matched with predictions of urban heat load under different Representative Concentration Pathways (RCPs) – a greenhouse gas concentrations trajectory. Scenario-based assessments from urban climate models following "business as usual" (RCP8.5), as well as climate protection (RCP4.5) are available from ZAMG and have been presented in the latest APCC Special Report (2018). These predictions correspond to different numbers of future annual excess heat and cold days in different parts of the city. Part two illustrates potential health impacts in the future given changes in population structure and composition and the climate under different scenarios.

Demographic Differential Vulnerability

Going beyond the scope of previous research, we consider the three components of vulnerability (i.e. exposure, sensitivity and adaptive capacity) in our analysis of health impacts. We combine the environmental and population science perspectives to analyze the role of demographic characteristics in past and future risks from exposure to climatic hazards. More specifically, we focus on the health effects of extreme temperatures by age, gender and education at the district level of Vienna and its surrounding areas. While other studies have looked at health impacts due to heat extremes at the city level (Muthers, Matzarakis, and Koch 2010), they typically do not consider differences and changes in demographic composition within cities.

In the case of the districts of Vienna, not only is there spatial heterogeneity in the degree and speed of aging, but also in the education structure of the population. Figure 3 shows the proportions of population by level of educational attainment for the districts of Vienna. While well above 40% of the population in the Inner City of Vienna, Neubau, Alserstadt and Josefstadt have high (post-secondary) education, in Simmering and Favoriten this proportion is only 15%. These vast spatial differentials have been shown to be strongly related to vulnerability from temperature anomalies both at individual and community-level (Wanka et al. 2014). By incorporating for the first time education into population projections for the metropolitan area of Vienna, assessment of future vulnerability and adaptive capacity to weather extremes will be improved substantially.

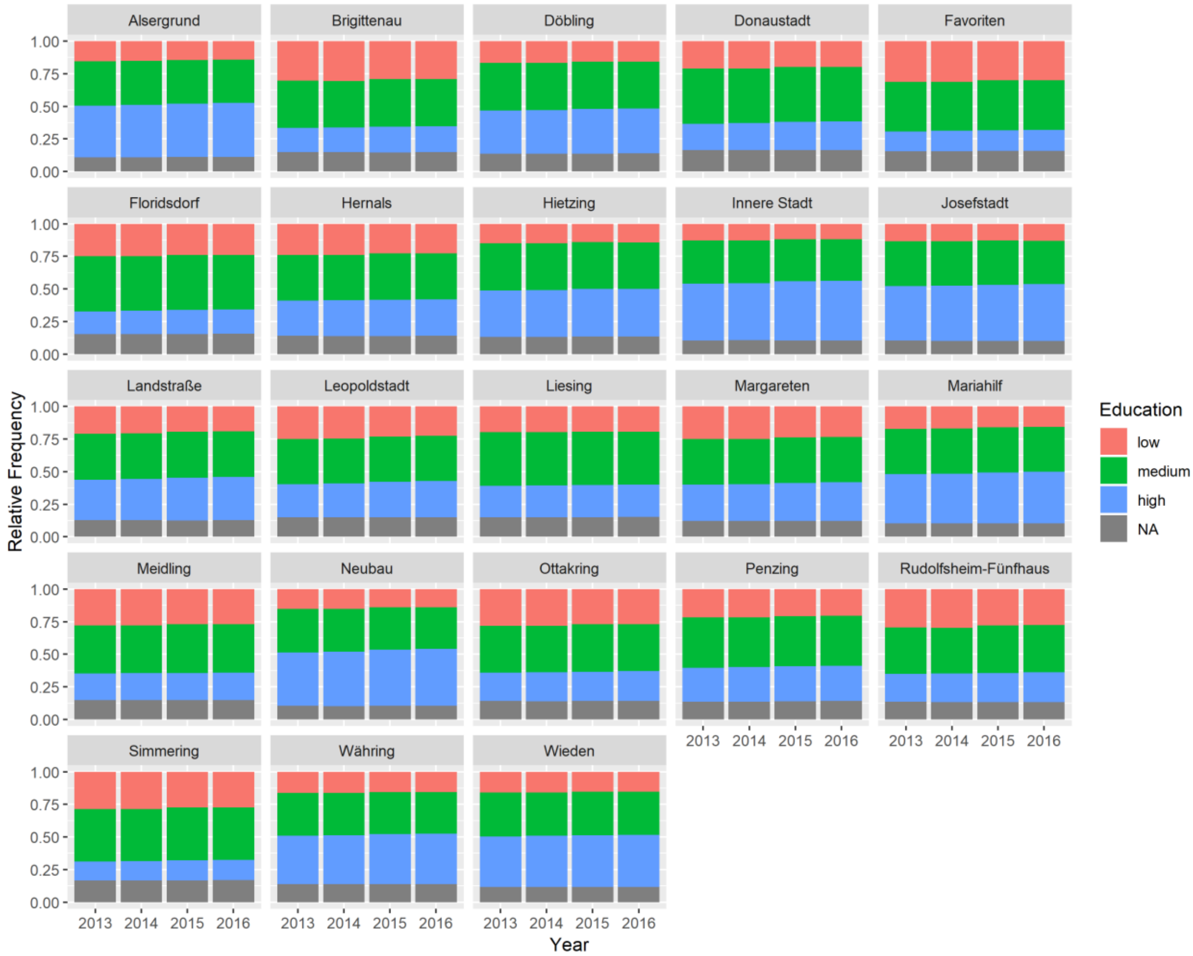

Figure 3. Proportion of population by level of educational attainment (ISCED 2011), districts of Vienna (2013-2016).

Moreover, to assist long-term planning to mitigate climate impacts on health, our study is one of the first to combine population and climate projections on a small spatial scale. In our forecasts, we will analyze different climate and population scenarios at the sub-national level to capture the effects of different future developments underlying demographic differential vulnerability. Another novel aspect is the consideration of infrastructural characteristics of the urban living spaces which influence exposure, as well as the degree to which they can be modified. As shown in Figure 4, of the 41,487 ha that are covered by the City of Vienna 35.6% are buildings, 45.5% are green areas, 4.6% is water and 14.3% are traffic surfaces. Of the 45% of roofs in Vienna that are appropriate for planting low vegetation only 2-3% are currently being used to reduce the UHI effect (Žuvela-Aloise et al. 2018). Using a scenario-based approach, we look at the potential to reduce health impact from different types of interventions in the urban environment. To the best of our knowledge, there is no other study so far that considers climate effects on health in conjunction with the characteristics of the exposed population and the built environment.

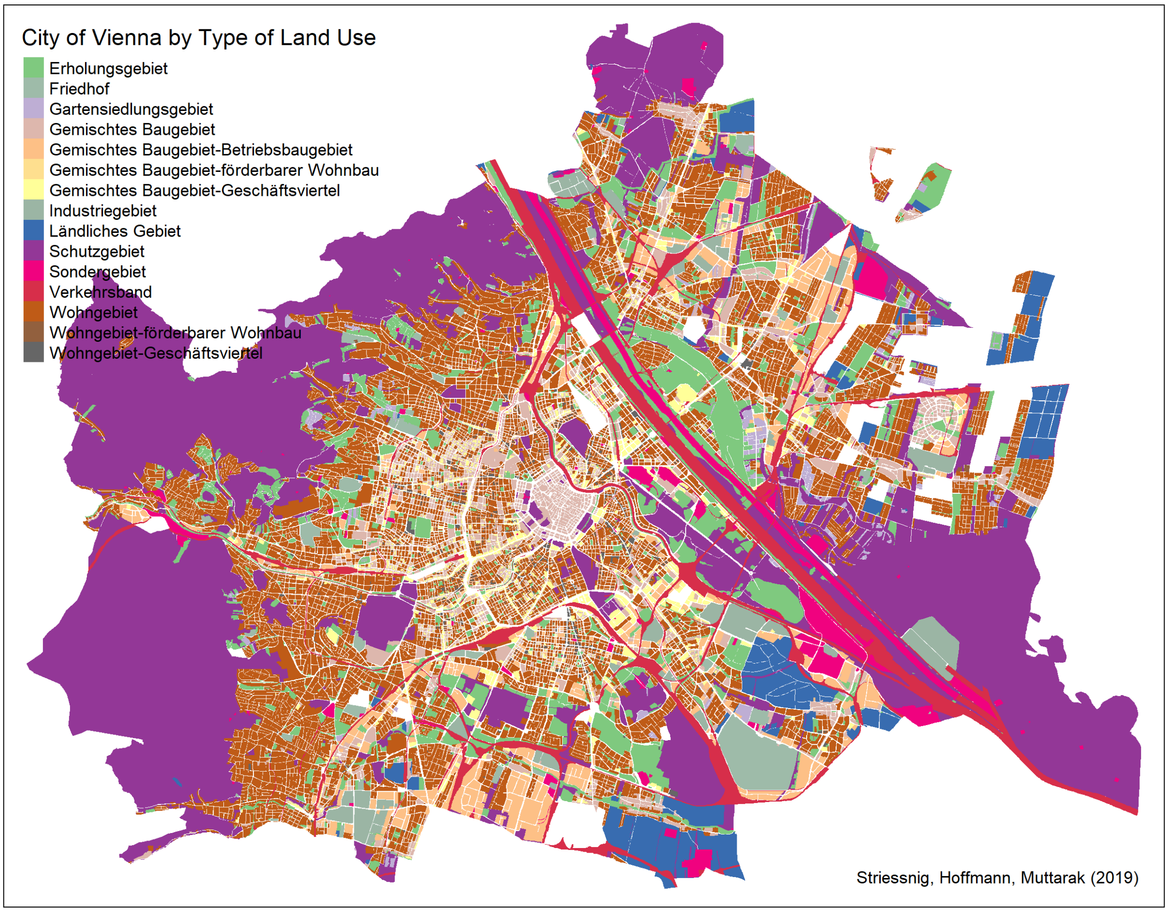

Figure 4. City of Vienna by type of land use. Source: MA 21.

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